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Active Light Shaping using GPC

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Abstract: Generalized Phase Contrast (GPC) is a light efficient method for generating speckle-free contiguous optical distributions using binary-only or analog phase levels. It has been used in applications such as optical trapping and manipulation, active microscopy, structured illumination, optical security, parallel laser marking and labelling and recently in contemporary biophotonics applications such as for adaptive and parallel two-photon optogenetics and neurophotonics. We will present our most recent GPC developments geared towards these applications. First, a compact GPC Light Shaper implementation based on our latest theoretical derivations is used to demonstrate the benefits for typical applications where lasers have to be actively shaped into particular light patterns. We then show the potential of GPC for biomedical and multispectral applications where we experimentally demonstrate the active light shaping of a supercontinuum laser over most of the visible wavelength range.

Keywords: Generalized Phase Contrast, Active Optics, Light Shaping

GPC Light Shaping

Arbitrarily sculpting light for both fixed and programmable shapes has a variety of applications in both research, industry and medicine. With the widespread use of lasers that lend themselves to efficient reshaping due to their spatial coherence, light's versatility is further increased. Hence, laser beam shaping based on photon efficient phase-only methods are extensively applied in research such as in active microscopy, optical trapping and manipulation [1,2]. Light shaping is also finding its use in novel and exciting applications such as contemporary neurophotonics and two-photon optogenetics [3] which applies the most advanced optical tools for exploring neuroscientific challenges. Outside the research labs. efficient light shaping

is also desirable for applications such as laser machining, lithography and laser-based digital cinema to name a few. These diverse applications all require light to be shaped in a plurality of ways [4]. For example, the illuminated optical window of spatial light modulators, used for both optics research and consumer display projectors, have a rectangular form factor. A variety of shapes bounded by steep edges and particular point spread functions are desirable in laser cutting and engraving. In two-photon optogenetics [5], it is a key aim to selectively illuminate intricate patterns of dendrites or axons within neurons, preferably with minimal loss of light and maintaining speckle-free light excitations even within turbid media.

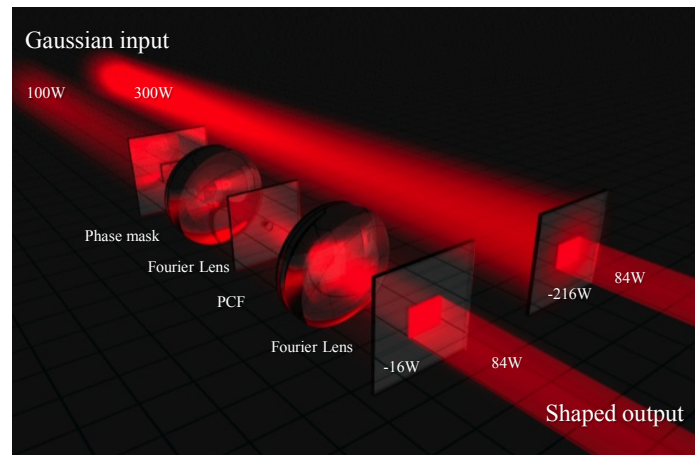


Figure 1: GPC efficiently transforms an incident Gaussian beam into a bright shaped output. Besides a standard imaging or telescopic $4f$ setup formed by two Fourier lenses, GPC only needs a simple binary phase mask at the input and a binary phase contrast filter at the Fourier plane. For comparison an amplitude masking configuration is shown besides the GPC Light Shaper to illustrate the significant difference in energy utilization when aiming for the same shaped output. (Figure adapted from [6])

Laser sources typically exhibit a Gaussian intensity profile. Shaping such a beam with the commonly applied hard truncation is inherently highly inefficient. It is well known that more than two thirds of an incident power will be lost when homogeneously illuminating a rectangular aperture with an expanded Gaussian beam [6-8]. To complicate things, this lost light power will inherently contribute to device heating that can either shorten device lifespan or require additional power for active cooling. Besides the obvious disadvantages of light inefficiency, the high price tag of advanced laser sources, such as femtosecond lasers or supercontinuum sources, used for multi-photon excitation, multi-spectral biophotonics and other state-of-the-art experiments, demands efficient use of the available photons

GPC (for Generalized Phase Contrast) belongs to the class of non-absorbing common path architectures [9]. A phase-only aperture directly representing the desired output intensity is mapped through the interference of its high and phase-shifted low spatial frequencies. This is achieved by phase shifting the lower spatial frequencies through a binary phase contrast filter (PCF) at the optical Fourier plane (cp. Fig. 1). GPC can thus be implemented with binary phase plates that are inherently simple to mass-produce with standard foundry processes common for silicon devices or microelectronics. The use of a one-to-one mapping geometry in GPC avoids dispersion effects which makes it advantageous for use with multiple wavelengths [10,11], spectrally broad light sources or for temporal focusing which can effectively confine light along the axial direction.

Experimental demonstrations

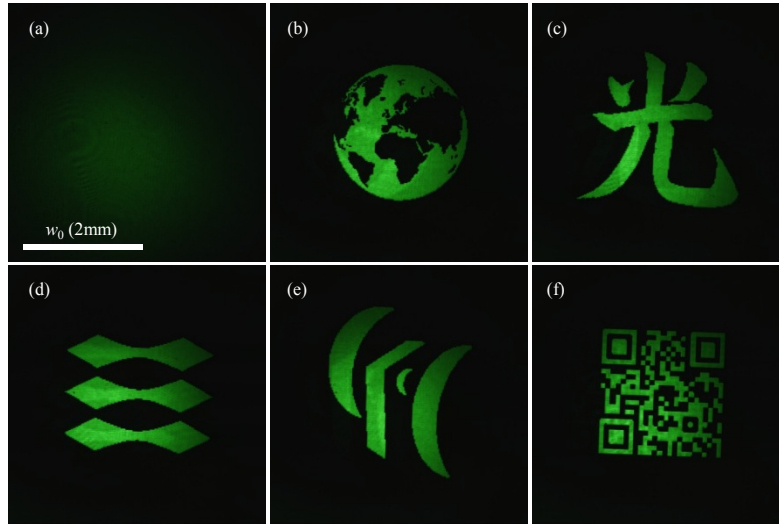


Figure 2: Experimental patterns generated by a GPC Light Shaper designed for 532 nm and using an active phase-only SLM (Figure adapted from ref. [7]).

To demonstrate speckle-free and contiguous GPC light shaping we used binary bitmap images directly displayed on a phase-only LCoS spatial light modulator mapped to 0 and π phase shifts. Dynamic GPC light shaping results for various shapes are shown in Figure 2 together with the unmodulated Gaussian for comparison.

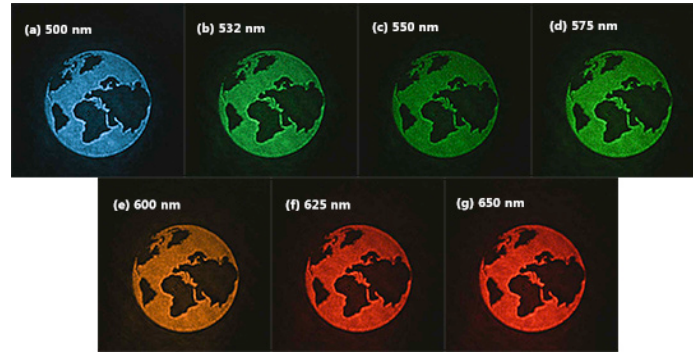


Figure 3: GPC light shaping a super continuum source showing color CCD images of GPC projections as the wavelength is varied from 500nm-650nm (Figure based on results from ref. [11]).

Figure 3 experimentally demonstrates GPC light shaping of a super continuum source and hence confirms the capability to efficiently shape light using a binary-only phase mask over a broad range of wavelengths.

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